Very Large Hadron Collider

at Fermilab

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National VLHC Collaboration
(Cornell, BNL, FNAL, LBL)

Technical Progress
- Low Field Option
- High Field Option

How & when we'll make it happen:

→ Main Injector	→ NUMI	→ 3 TeV	→ VLHC
'94	'99	'02	'07

National VLHC Collaboration

←NSF→ ← DoE →

Cornell BNL FNAL LBL

Steering Committee: Dugan, Harrison, Peggs, Limon, Malamud*, Barletta, Siegrist

- *Site Specific* at *Fermilab*
- Develop & Evaluate Technical Options
- Develop Common Cost Methodology

Working Groups:

- Accelerator Physics
- Magnets
- Accelerator Systems

Possibility of Internationalizing Collaboration at next ICFA Meeting (FNAL Oct '99)

Snowmass Definition of VLHC

Energy:	50 TeV/beam (100 TeV E_{CM})
Luminosity:	10^{34} cm^2/sec
Collider:	P-P
Injector:	3 TeV, rapid cycling.

This talk will focus on:

3 TeV, Low Field Injector

- Same Technology as 50 TeV machine
  (Low or High Field)
- Near-Term Demonstration Project
- Provides Cost Basis for 50 TeV Approval

Two VLHC Design Approaches

1. High Field Strategy:

Pick Up factor of 1.5

(if 14 Tesla magnets could be manufactured for same price as 9 Tesla magnets)

3 TeV Injector fits on site

(but final machine does not).

Synchrotron Radiation Damping

Scales as $E^2 * B^2$
Makes design insensitive to initial emittances.
Gains factor ~2 in integrated luminosity.
Kills cold-bore design for E>50 TeV.

Challenges:

Present conductor costs >10x higher
Magnetic forces proportional to B^2.
AC Losses for rapid-cycling 3 TeV injector
Cold bore presents many problems even at LHC energies

2. Low Field Strategy:

Warm Iron, Warm Bore Magnet

- Simple vacuum system works at higher energy

Pick up factor of ~40 in superconductor usage:

- Factor 10 from SC current density at low field
- Factor of ~2 from iron
- Factor of ~2 from “thick coil” effects

Simple design: Transmission Line Magnet

- Single-turn magnet
- Non-Critical conductor placement
- Simple Cryogenic system
- Low cold mass, low heat leak
- Small Stored Energy

Challenges

- Tunnel size for 2 Tesla magnets
  - (1 mile of Radius per TeV)
- Beam Dynamics at Injection Energy
  - (solutions are apparent)
- Demonstration of magnet economics
  - (string test & demonstration machine)

MAGNET COSTS

Today’s advertised cosine-theta magnet costs:

$2.5k - $5k per Tesla-Meter

➔ $100M-$200M/TeV E_{BEAM} for P-P machine

Only Published Magnet Cost (that I could find)
(HERA; IEEE Trans. Mag.32 #4,1996)

$\boxed{\$4k/T\text{-}M}$

Magnet Costs are Materials Cost Dominated:

70% to 90% of magnet costs are M&S.

➔ A good estimate for the magnet cost can be obtained from the M&S costs.

How do you build magnets efficiently?

Use same procurement strategy as Main Injector magnets.

- Purchase finished subassemblies from vendors
- Fermilab performs final assembly & checkout
- Fermilab assumes technical responsibility

  NO GENERAL CONTRACTOR

  (this strategy produced magnets ahead of schedule & under budget)

What does the Low-Field Magnet Cost?

Cost Methodology

Vendor quotes obtained for key components.

Magnet designed with proven, commercially available processes:

- Stamped, Laminated, half-cores assembled commercially (same vendors as Main Injector)
- Commercial NbTi strand (multiple vendors)
- Structure pieced together from 40ft lengths of commercially available components: SS pipe, structural tube, extruded aluminum, etc.

The M&S production costs for the prototype cross section you see outside are ~$300/T-m.

This extrapolates to ~$400/T-m for assembled and tested magnets.

The transmission line magnet has a good shot at being 10x less expensive than today's magnets.

Conductor Costs and Operating Temp.

1) Traditional Tradeoff between:

- Cryogenics Costs (favoring high T_{OP})
- Superconductor Costs (favoring low T_{OP})
- Operating Field (mandating low T_{OP})

2) Dramatic Improvement in conventional NbTi Superconductors in last 10 years:

- Improvement mainly at low field

  (driven by MRI applications)

- Overall cost of strand has dropped to ~$85/lb.

3) The Transmission Line Conductor Operates at B~0.8 Tesla (iron pole tips are at 2T).

→ The cost-optimal operating temperature for the transmission line magnet is 6.5~7K.

This permits a simple and inexpensive cryosystem

TODAY’S TUNNEL COSTS

Conventional Tunnel Cost Estimate

Estimate by Kinney Construction

(major Chicago Deep Tunnel Contractor)

34km Circumference for 3TeV Low Field

12ft Diameter

Concrete Slip Lining

Two (or Four) large shafts

Transfer Lines from Main Injector

Cost: ~$150M

➔ Acceptable for 3 TeV injector project

➔ Plan R&D Program to further reduce costs

INSTRUMENTATION

This is not a major cost item.

System should be simple and modular to permit easy maintenance.

ELECTRONICS "LUMP" every ½ cell (~75m)

- Network connection
- Beam Loss Monitor & Beam Abort Logic
- Beam Position Monitor
- Correctors
- Ion Pump HV supply
- Vacuum Gauges, gate valves
- Cryo Monitoring/controls

Lump is in Shoebox-sized chassis in shielded hole-in-the-wall.

GOAL FOR NEXT FY IS TO PROTOTYPE "LUMP" USING TODAY's TECHNOLOGY

VACUUM SYSTEM

Warm Bore Vacuum System

→ insensitive to synch radiation >100 TeV

→ Conventional “Electron Machine” vacuum system

- Extruded Aluminum Beam Pipe
- Side Chamber with NEG strip pumping
- Lumped Ion pumps

  (for Methane & Noble Gasses)
- Low Temperature Chemical Bake-out
- Bellows-Free installation planned

  (extrusion is pinned to iron support tube)

Collaboration and Technical assistance from KEK

(Prof. H Ishimaru)

POWER SUPPLIES AND QUENCH PROTECTION

3 TeV machine is a 2-Terminal device

Low inductance of 1-turn magnet does not require:

- Distributed power supplies.
- Distributed dump resistors.

Single set of 75kA current leads required.

Single 75kA/150V supply required.

(~1/4 of Main Injector)

Quench Protection

Single 80MJ dump resistor.

1 Second dump time constant

+/-2.5kV to ground

CONCLUSIONS:

1) The VLHC collaboration has identified promising paths to affordable future hadron colliders.

2) Both low-field and high-field approaches are under active development at Fermilab.

3) Fermilab is the right place –world-wide– to preserve and strengthen the development of superconducting magnets.

4) Expect to see a serious, low-cost proposal for a 3 TeV rapid-cycling injector in the next 1-2 years. This is a necessary and sufficient step to ensure the future health of HEP at the energy frontier.